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**EFFECTS OF KNOWLEDGE OF RESULTS AND DIFFERENTIAL MONETARY REWARD
ON SIX UNINTERRUPTED HOURS OF MONITORING**

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FOREWORD

This report was prepared in the Aviation Psychology Laboratory, Department of Psychology, University of Illinois, Urbana, Ill., under contract No. AF 41(609)-1481 and task No. 775504. It was monitored by Dr. Bryce O. Hartman, Psychiatry Branch, USAF School of Aerospace Medicine. Dr. Jack A. Adams was principal investigator. The paper was submitted for publication on 14 June 1965. The work was accomplished between April and October 1964.

This report has been reviewed and is approved.

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ABSTRACT

The effects of knowledge of results (KR) and monetary reward on six hours of uninterrupted monitoring of a complex visual display were examined. Comparisons were made among groups receiving: no KR, about response adequacy, KR, KR plus monetary reward or penalty determined by response adequacy, and KR plus reward in practice but not during the criterion session. In addition, comparison was made between the no-KR group and a similar one run by Webber and Adams (1), where a rest had been given after three hours of a six-hour monitoring period. All groups showed performance decrements of small magnitude. The manipulation of KR and reward failed to deter decrement; however, reward in addition to KR did enhance overall performance. KR alone did not facilitate performance, contrary to results from other studies. Training under KR plus reward did not enhance criterion performance when no KR or reward was provided. In support of previous research, man's monitoring capabilities over extended time periods seem adequate for modern systems.

EFFECTS OF KNOWLEDGE OF RESULTS AND DIFFERENTIAL MONETARY REWARD ON SIX UNINTERRUPTED HOURS OF MONITORING

I. INTRODUCTION

Typically, vigilance tasks used in the investigation of monitoring behavior are relatively unstructured. The subject knows only that he is to detect signals whenever they occur. Generally, no information is given to the subject about the adequacy of his performance. In addition, the signals to be detected are aperiodic and transient and are often missed. Missing a signal effectively increases inter-signal interval, a factor which often results in performance decrement (2, 3, 4). The aperiodicity or temporal uncertainty of the signal also is an important variable in effecting vigilance decrement (2, 3). If monitoring behavior can be considered to be an acquired skill, such conditions would not be conducive to the development and maintenance of high levels of proficiency. Rapid skill development depends, to some extent, on greater structuring and guidance in task performance. It is widely recognized that knowledge of results (KR), or feedback, is useful for this purpose, especially in the early stages of skill acquisition (5). Therefore, a closed-loop system is necessary rather than the more or less open-loop system typical of the task used in most vigilance studies. Feedback, which is typical of closed-loop systems, has been found to produce higher performance levels in vigilance tasks (2, 6, 7) and, under some conditions, reduces or eliminates the decrement (2, 8). The means by which KR has its effect on performance is unknown. Such results might be attributed to the "arousing" effects of additional stimulation from the feedback (9). It appears that to be effective, feedback should indicate the proficiency of the subject's performance. Adams and Humes (10) gave different groups informative and uninformative feedback about task

proficiency, and only informative feedback had significant effects. In skill performance, some of the effects of such feedback seemed to be motivational (11), which also may be true for vigilance (12). On the other hand, Fitts (5) indicates that KR might improve the discriminations made by the subject in regard to his general strategy or cognitive set. If such discriminations are acquired in vigilance tasks when KR is provided, the effects should be relatively long lasting. Adams and Humes (10) and Wiener (7) found that practice on a monitoring task when KR was given transferred to a no-KR criterion session. If KR acted primarily as a motivational stimulus, such results would not be expected. Performance should deteriorate on the removal of feedback; therefore, whether KR produces new learning or affects only the level of motivation is still an open question. The present experiment is directed at certain problems surrounding the use of KR in monitoring performance.

Various groups receiving different conditions of KR were compared among themselves and with a control group receiving no information about performance proficiency. Monetary reward has proved to be an effective incentive to superior performance (13). In an attempt to manipulate motivation, one group of subjects was monetarily rewarded or penalized after each signal in terms of the adequacy of response. Their performance should be superior to subjects receiving the same information about performance but no incentive reward, and to subjects receiving no KR at all. In addition, if discriminative habits are acquired during the initial vigilance performance, they should transfer to performance made without such feedback (7, 10). The addition of incentive reward to KR may enhance such effects.

A group differentially rewarded or penalized after each signal during a practice, but not during a criterion session, was compared with the no-KR group to ascertain whether transfer of training occurred.

Previous research involving six hours of monitoring reported by Webber and Adams (1) used the same task as the one used in this experiment. In their procedure the six-hour monitoring period was divided into three-hour sessions and the subject was allowed a short break. Such breaks may provide for some reduction in performance decrement (8, 14, 15). A direct comparison was made between one of the groups run by Webber and Adams and a comparable group of subjects in this study. In fact, the criterion session for all groups was unbroken and represents a considerable extension of uninterrupted monitoring time beyond that used, typically, in vigilance studies.

In summary, the present study compares a number of groups of subjects receiving different treatments to assess the effects of KR, KR with additional monetary reward, and transfer of training under conditions of KR and monetary reward, and the effects of a short break on six hours of visual monitoring.

II. METHOD

The method and procedures used in this experiment were very similar to those used by Webber and Adams (1) and Montague et al. (16). More detail about the apparatus and methods used can be obtained from those reports.

Apparatus

Two units of the Complex Visual Monitoring Task were used, with each unit in a separate room for running 2 subjects simultaneously. The display consisted of three rows of four digital display boxes and was arrayed in front of each subject in a 60-degree arc. A standard reference number appeared in each row (i.e., 40, 50, and 60, from top to bottom, respectively). A change in one of the numbers on one

of the twelve boxes was the critical signal to be detected.

An armrest switch was depressed continuously by the subject, who released it only on detecting a signal and then pressed a detection button 18 inches from the rest position. When a signal occurred, timers started at the experimenter's remote station. The release of the armrest switch stopped one timer, yielding a measure of *Detection Latency*, and started another timer. The second timer was stopped by depression of the detection button, which yields *Motor Movement Latency* measuring motor-transit speed between the armrest position and detection button.

The experimenter and the scheduling and recording apparatus were in another room. The signals were preprogramed on punched paper tape, which was stepped automatically through a reader.

Knowledge of results was provided by a small panel of lights situated immediately in front of the subject. Four lights were provided, all of different sizes and colors in a vertical array. The top light indicated "superior" performance, the second, "adequate" performance; the third, "poor" performance; and the fourth indicated a missed signal. Specification of the meaning of these categories will be undertaken below. Switches in front of the experimenter operated the lights and corresponding counters, which were used to obtain the total number of times a subject received feedback in each of the four categories. Figure 1 shows the subject's display.

Experimental design

The design provided for different treatments for independent groups of subjects. One group, which acted as a control group for all comparisons, received no knowledge of results during either the practice or criterion sessions. The conditions for this group were identical to those for the ON group described by Webber and Adams (1), except for the elimination of the short rest period provided after three hours

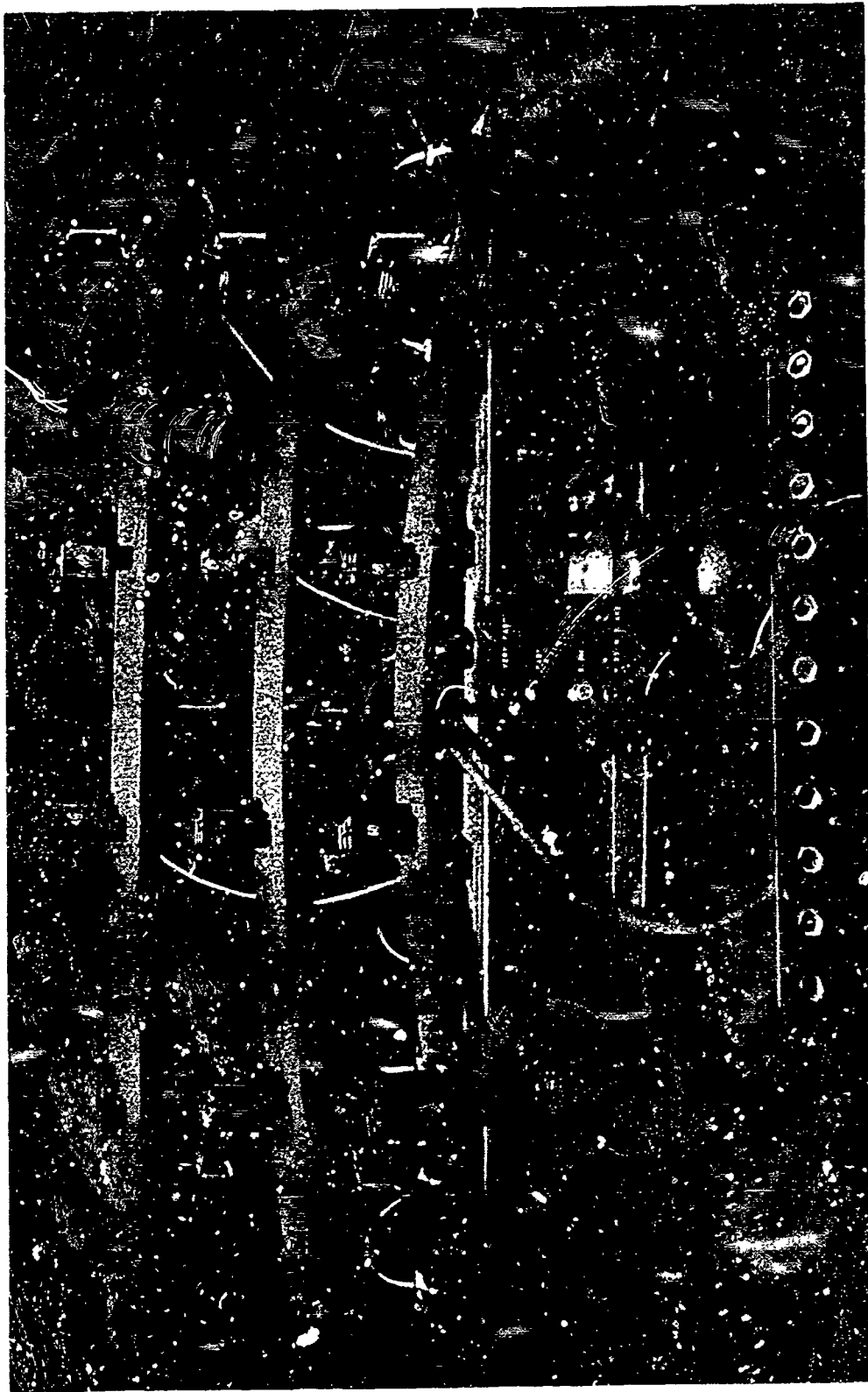


FIGURE 1

The subject's displays for the Complex Visual Monitoring task. Critical signals were changes in one of the twelve numeric display boxes. The KR was provided by the light panel in the foreground. Superior, adequate, or poor performance, or a missed signal was indicated by the very fast, fast, slow, or miss indicator lights. The point or monetary value for each category was provided to the left of each light.

in the earlier study. The previous study used 15 subjects in the ON group; for comparison purposes, the present group included a like number. This group will be referred to in this report as D-D. Any differences in performance between these groups may be attributed, at least in part, to the rest period introduced for the ON condition. The letters used to identify groups in the present experiment indicate task conditions during the practice and criterion sessions. The letter *D* indicates detection conditions without KR; *F* indicates that feedback or KR was provided, and *P* indicates that differential payment was given. *ON* has meaning specific to display conditions in the Webber and Adams study.

Three other treatment conditions were provided for other groups. One group, identified as the F-F group, was informed about the adequacy of their performance during both the practice and criterion sessions. Another, the FP-FP group, was given differential monetary reward or penalized in terms of the adequacy of their performance. The transfer group, referred to as FP-D, received feedback and differential payment during the practice session only and no information about performance proficiency during the criterion session. Therefore, comparisons are made between groups for the KR and rest-period-condition treatment. The intersignal intervals, as well as the position of the signal on the display, were varied during the sessions. A comparison of treatments is made within subjects.

Procedure

All subjects had a three-hour practice session between 1 to 5 days prior to the criterion session of six uninterrupted hours of monitoring. The three-hour session was considered ample time for the subjects to learn the task requirements. A signal rate of 16 signals per hour was used. This is the same rate as used by Webber and Adams (1) and in the slow-rate conditions by Montague et al. (16). The vigilance sessions were divided into 45-minute trials with four trials during each three-hour period. This was done for convenience in programming and analysis. The subjects received no

indication of this procedure. During each trial, 12 signals occurred. The amount of change in the number displayed, the position at which the change occurred, and the intersignal interval were separately and randomly assigned on each trial. The mean intersignal interval was 219 seconds averaged across intervals of: 14, 30, 60, 120, 290, 420, 600, and 900 seconds. Each critical signal persisted for 6 seconds.

The subjects were randomly assigned to the various groups as they appeared for the practice session. Two subjects were run simultaneously, whenever possible. They were given detailed instructions regarding the task and several demonstration trials before practice began. Any serious errors of procedure were corrected at this time. The instructions for the groups receiving the feedback conditions specified the meaning of the various performance adequacy categories indicated by the lights. On the basis of the data obtained in the previous experiments with the same task (1, 16), a frequency distribution of Detection Latency scores was obtained. From this distribution, *superior* performance was chosen to be responses which occurred in less than 750 msec. About 5% of the responses on the distribution were faster. *Adequate* performance was defined as a Detection Latency between 760 msec. and the median of the distribution, 1,750 msec. Detection response latencies slower than the median were designated as *poor*. The subjects in the simple feedback condition (F-F) were told that points could be earned or lost by responses falling into the various categories. Superior performance gained them 10 points; adequate performance, only 1 point. They lost 2 points for poor performance and 10 for missing a signal altogether. They were instructed to work toward a high point total, which would result from rapid responding and constant attention. The subjects in the feedback-payoff conditions (FP-FP, FP-D) were given the same instructions except that they were told that each point was worth a penny. If they responded very quickly to a signal, they would earn a dime; if they missed a signal, they would lose a dime. After the practice session, the subjects were scheduled for the criterion session and dismissed. Prior to the criterion

session, they were given brief instructions reminding them of their task condition. Then they entered the experimental room for six hours. Using one-way windows, the experimenter made frequent checks to ascertain any violation of procedure. For example, if a subject was asleep or drowsing, he was warned by use of the intercom. He had been informed prior to the experiment that he would be dismissed if more than one warning was necessary. None was dismissed.

Subjects

Forty-five male undergraduates served as subjects. They were paid for their participation. There were 10 subjects in each of the three feedback treatment groups and 15 subjects in the comparison control group (D-D). The data for 15 additional subjects chosen in a similar fashion were obtained from Webber and Adams (1).

III. RESULTS

The results were analyzed in two parts. An overall analysis included data from the four groups in this experiment along with data taken from the ON group run by Webber and Adams. In order to simplify the analysis, 10 subjects were selected at random from the 15 in the D-D and the ON groups. The first analysis of the data, therefore, compared five groups of 10 subjects each. A second analysis which compared the ON and D-D groups alone utilized the data from all 15 subjects run in those conditions and will be discussed below. Only the tests for main effects or interactions which were significant at or beyond the .05 level will be reported in detail.

Analyses comparing the error and latency data obtained from all groups during practice revealed no overall difference among the treatments. Neither was there a significant change in performance during the three-hour practice session. Performance of the subjects during the criterion session is in substantial agreement with previous reports (1, 16-19). The proportion of errors of omission made during the session was moderate, averaging about 9%. The

proportion of signals missed, however, did increase as a function of monitoring time or trials, $F(7, 315) = 3.082, P < .001$. The mean proportion of errors (signals missed) is shown in figure 2 for each group as a function of blocks of trials. Although the analyses involved data for 45-minute trials, data were averaged for two trials in order to reduce some of the variability in plotting the trial-by-trial data. The apparent differences among the groups are not statistically reliable.

On the other hand, analysis of the Detection Latency (DL) data revealed significant group differences, $F(4, 45) = 2.747, P < .05$. Also, a significant performance decrement is revealed by the increase in DL with trials, $F(7, 315) = 2.798, P < .01$, which is in agreement with previous studies (1, 16, 18). Independent comparisons among the group means (all tested at $P < .05$) revealed the D-D group to have performed significantly poorer than the FP-FP group. The FP-FP group also displayed significantly faster latencies than the F-F group. No other differences between group means were significant. Similar results were obtained in the analysis of Motor Movement Latency (MML). An overall significant difference among groups, $F(4, 45) = 2.747, P < .05$, was due primarily to the difference in motor-transit time between the FP-FP and D-D groups as revealed in the independent comparisons. The differences between the other groups were insignificant. The MML was found to increase reliably as a function of trials, $F(7, 315) = 3.054, P < .01$, a result which agrees with those of previous studies. Thus, it appears that there is a definite reduction in the speed with which subjects can react with progressive extension of monitoring time. As has been noted earlier (1, 16), however, the magnitude of the decrement in both DL and MML is relatively small. The maximum change in DL during the six-hour period is approximately 300 msec., while MML changes less than 100 msec.

Following a procedure used in earlier studies (1), we combined the error and DL data to yield a measure of total detection performance. In this procedure, errors (judged as poorest performance possible) are given a value of

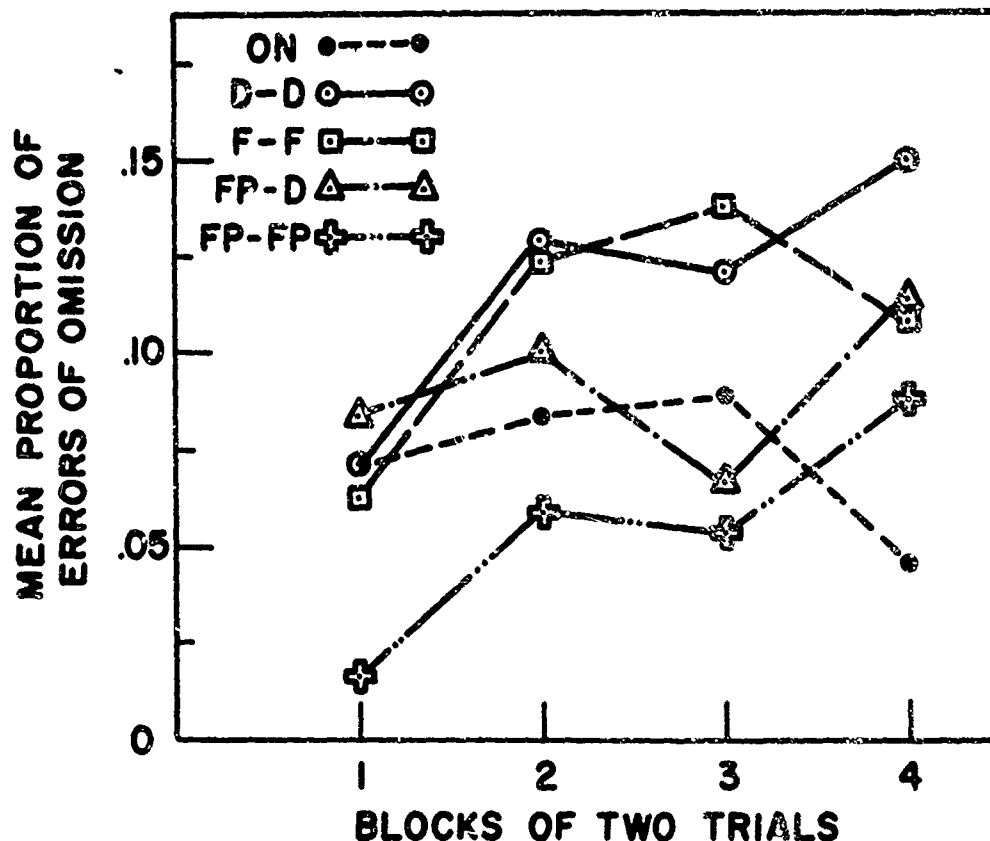


FIGURE 2

Mean error proportions made by the different groups as a function of blocks of two trials. The letters indicate experimental conditions: F indicates feedback about performance was given; P indicates differential reward; D indicates that no feedback or reward was given. ON represents data taken from Webber and Adams (1964).

zero and averaged with the reciprocal of DL, thus yielding mean *Reciprocal Detection Latency* (RDL). The RDL provides a readily comprehensible measure of total vigilance performance. In addition, since it includes data from every signal occurrence, it allows direct analysis of the effects of the length of the interval between signals and the position of the signal on the display. Position was evaluated by comparing performance on the four corner displays with the two center units and with the six in between. Thus, position is defined roughly in terms of relative distances from a central fixation point (1, 16). Figure 3 displays the mean RDL's for each group as a function of blocks of two trials for both the practice

and criterion data. A three-way analysis of variance, with Groups as a between-subjects variable and Trials and Position as within-subjects variables, was performed by using the RDL scores. A significant amount of variance is attributable to Groups, $F(4, 45) = 6.995$, $P < .001$; Trials, $F(7, 315) = 7.348$, $P < .001$; Position, $F(2, 90) = 38.19$, $P < .001$; and there was a significant Trials x Position interaction, $F(14, 630) = 2.524$, $P < .005$. The significant performance decrement over trials agrees with that found in previous studies. Multiple comparisons between the individual groups in terms of the mean RDL scores revealed the same differences as those comparisons made after the analysis of DL. Only the

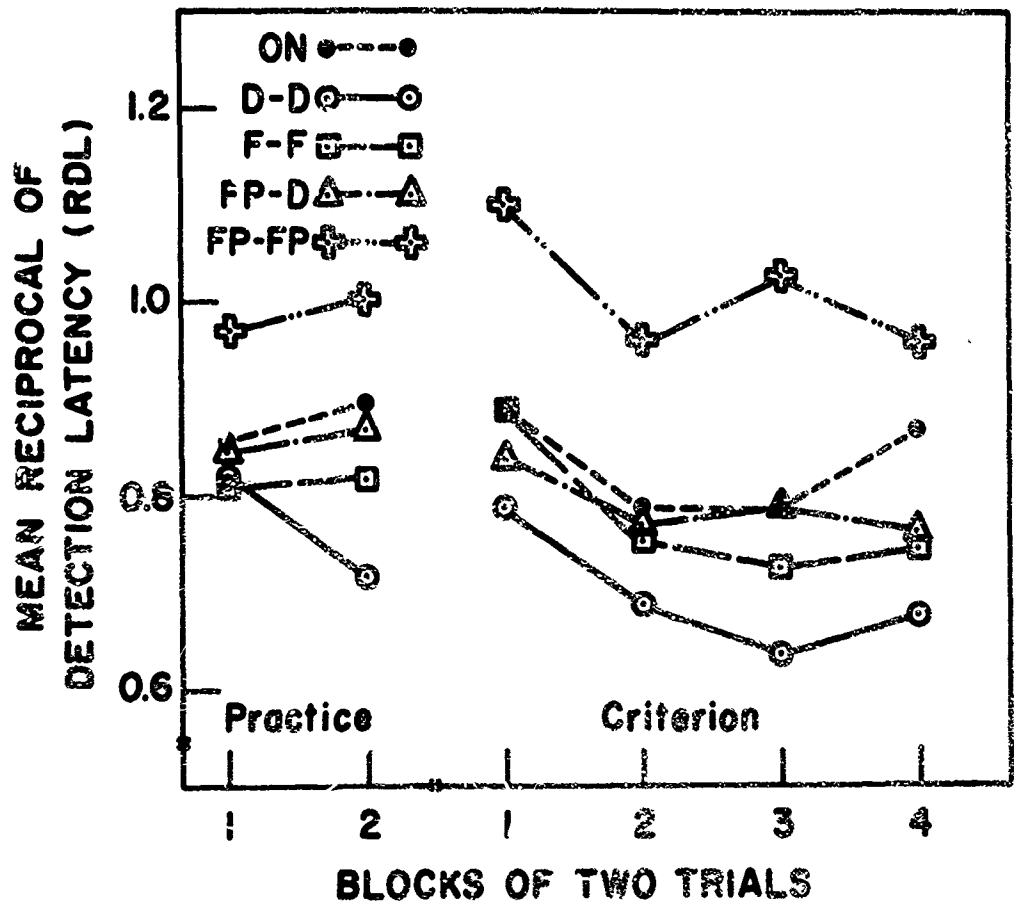


FIGURE 3

Mean Reciprocal Detection Latency curves are shown for all groups for both practice and criterion sessions.

D-D and FP-FP groups, and the F-F and the FP-FP groups differed significantly ($P < .05$).

As had been found in the earlier experimentation, the position of the signal in the display is a significant variable. Detection performance is poorer for the peripheral display units. In addition, although the Trials \times Position interaction accounted for about 3% of the within-subjects variance, the rate of decrement over trials may be greater for the more peripheral than for the central display units. A similar finding was reported by Montague et al. (16) and may indicate a deterioration in the scanning activity of the subject.

Another three-way analysis was performed, abstracting the variance due to Intersignal Interval instead of Position. The Groups and Trials effects were significant as they had been in the previous analysis. Intersignal Interval produced reliable differences in performance, $F(7, 315) = 10.71, P < .001$; and the Trials \times Intervals interaction was significant, $F(49, 2205) = 2.029, P < .005$, although accounting for only 2% of the within-subjects variance. Overall performance declined as a function of intersignal interval in agreement with other studies (1, 2, 12, 16). Although the FP-FP group performs better than all the others, the only significant differences are between it and the D-D and F-F groups ($P < .05$).

Separate analyses were made on DL, MML, errors of omission, and RDL for all 15 subjects in the no-feedback control group (D-D) and those from the ON group from the Webber and Adams study. The only obvious difference in procedure between the groups was the lack of a short rest period for the D-D group. Reliable differences between the groups exist across all measures with the ON group generally displaying superior performance. On the other hand, no overall decrement in DL or errors occurred across trials. The change in MML and in RDL over trials is significant. Once again, position in the display and intersignal interval contributed significantly to the variance. The differences between the groups would seem to indicate that the short rest period improved the performance for the ON group. Separate analysis of their practice data indicated, however, that the groups may have been different initially. The difference between the groups during practice, in terms of DL, just falls short of significance at the .05 level and is significant at that level for the RDL data; therefore, it is doubtful that the difference between the groups can be attributed to the rest interval alone.

IV. DISCUSSION

The results demonstrate once again that man can maintain relatively high levels of vigilance performance over extended, unbroken monitoring periods. Although decrements were observed in terms of increasing frequency of errors and longer response latencies, the magnitude of the effect was small, and perhaps, practically inconsequential for many operational tasks of this kind. The attempt at reducing this moderate decrement by utilizing KR about performance adequacy and monetary reward produced somewhat equivocal results.

Constant feedback paired with differential monetary reward (FP-FP) raised the overall level of performance without eliminating the decrement over monitoring time. The reliable difference between the FP-FP and the F-F groups demonstrates the effectiveness of differential monetary reward as a motivational

variable. There is no indication that stable, discriminative habits were learned during practice. Training under feedback and payoff conditions did not improve criterion performance when no feedback was given (FP-D). This result is contrary to those of Wiener (7) and Adams and Humes (10), who found that training with KR transferred to the criterion session. This discrepancy may be due primarily to the incentive motivation provided by the differential payoff. Bergum and Lehr (13) observe that the facilitation of vigilance performance with monetary reward seems to be short-lived and may, when withdrawn, actually be detrimental to performance. Although no detrimental effect was found here, it is possible that the withdrawal of both KR and monetary reward during criterion performance produced negative incentive conditions.

Surprisingly, in view of the results of a number of other experiments, feedback about the adequacy of response to each signal did not produce superior responding or eliminate decrement. Experiments starting with Mackworth's in 1950 and including studies by Baker (2), McCormack (6), Wiener (7), and Adams and Humes (10), among others, had found superiority in performance for groups given KR; yet the F-F group in this study did not perform significantly better than the no-feedback group (D-D). These discrepant results may be due, in part, to differences in the experimental task involved in the present experiment. In all but the last study mentioned above, brief transitory signals were used, and missing a signal makes the apparent intersignal interval somewhat longer. Intersignal interval is an important determiner of performance, with longer intervals yielding poorer performance. The KR about responses to each signal eliminates this effect since, in all cases, a subject knows when a signal occurred. In the present task, signals persisted for 6 seconds; as a result, more than 90% of the signals were detected. Such a situation in itself provides some amount of KR and may have attenuated the difference between the feedback and no-feedback conditions. Adams and Humes (10) also used a complex task of this kind with persistent signals and did find reliable differences between

KR and no-KR groups. In their study, feedback was given quantitatively in terms of the difference (in milliseconds) between present response latency and the mean latency from the immediately preceding trial. In effect, a subject competed with himself from trial to trial. The KR, in the present experiment, was provided qualitatively (e.g., adequate, or poor) in reference to fixed standards established by the performance of groups of subjects run previously. Further experimental examination of the way these procedural differences produced the discrepant results would seem advisable.

Finally, an apparent sampling difference confounded the comparison of the group taken from the Webber and Adams study with the comparable group in the present experiment. The significant difference for RDL scores between the groups in the practice session indicates that the difference between the groups during the criterion session cannot be attributed solely to the rest period given to the

subject in the ON group. If the means for each trial are corrected in terms of the mean difference between the groups observed during practice, the curves are very similar. There is no indication of any difference in performance during the last three hours resulting from the short rest period. Therefore, it is not likely that the short rest periods allowed every three hours affected performance to any great extent in the studies of Webber and Adams (1) or of Montague et al. (16).

The observation of slight performance decrements on complex vigilance tasks with persistent signals is consistent among several experiments from our laboratory. The manipulation of KR and incentives may enhance performance to some extent but with considerable cost in terms of modification of the task situation. It would be impractical to attempt such modifications in real systems since the magnitude of the decrement is so small, unless no errors or delays in responding can be tolerated.

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